



NASA SBIR 2020 Phase I Solicitation

S3.06 Thermal Control Systems

Lead Center: GSFC

Participating Center(s): JPL, LaRC, MSFC

Technology Area: TA14 Thermal Management Systems

Future spacecraft and instruments for NASA's Science Mission Directorate (SMD) will require increasingly sophisticated thermal control technology. Innovative proposals for the cross-cutting thermal control discipline are sought in the following areas/scopes. Research should be conducted to demonstrate technical feasibility during Phase I and show a path toward a Phase II hardware demonstration. Phase II should deliver a demonstration unit for NASA testing at the completion of the Phase II effort.

Scope Title

Dust Mitigation Thermal Coatings

Scope Description

Thermal coatings are an integral part of a space mission and are essential to the survivability of the spacecraft and instrument. Coating of the radiator with desired emissivity and absorptivity on the radiator surface provides a passive means for instrument temperature control. The utilization of variable emittance devices further enables active control of the instrument temperature when the heat output from the instrument or the thermal environment of the radiator changes. With NASA's new initiative to return to the moon, a new coating technology that will keep surfaces clean and sanitary is needed. New coating formulations utilizing durable, anti-contamination and self-cleaning properties that will disallow the accumulation of dust, dirt and foreign materials are highly desirable. These coatings can have low absorptance and high IR emittance properties or be transparent for use on existing thermal coating systems. The goal of this technology is to preserve optimal long-term performance of spacecraft and habitation components and systems.

References

The following website provides links to some references for dust mitigation coatings such as lotus thermal coatings:

<https://ntrs.nasa.gov/search.jsp?R=20150020486>

Expected TRL or TRL range at completion of the project: 2 to 5

Desired Deliverables of Phase II

Prototype, Analysis, Hardware

Desired Deliverables Description

- Successfully develop the formulations of the coating that leads to the desired dust mitigation.
- Samples of the hardware for further testing at NASA facilities.
- Results of performance characterization tests.
- Results of stability test of the coating formulations and its mechanical durability test under the influence of simulated space and lunar environmental conditions.
- Final report.

State of the Art and Critical Gaps

There are limited options for durable, stable thermal control coatings that are dust shedding in charging environments. Current state of the art, sprayable radiation stable coatings are able to coat complex, irregular surfaces, but they are porous and will become imbedded with dust and particulates. Other surface films tend to be less optically stable and may charge in the plasma environment thereby attracting lunar regolith to their surfaces. Mirrors have the limitations of requiring flat surfaces and are not conformal in nature. Currently, no single thermal control surface appears to provide stability, durability, and meet optical property requirements for sustained durations in space and lunar environments.

Relevance / Science Traceability

Many Science Mission Directorate (SMD) missions will greatly benefit from this dust mitigation thermal coating technology: any lunar-relating project, and projects involved with robotic science rovers and landers.

Scope Title

Heat Pumps for High Temperature Sink Environments

Scope Description

Operations in extreme environments where the environment sink temperature exceeds spacecraft hardware limits will require active cooling if long duration survivability is expected. Robotic science rovers operating on the Lunar surface over diurnal cycles face extreme temperature environments. Landers with clear views to sky can often achieve sufficient heat rejection with a zenith or, if sufficiently far from the equator, an anti-sun facing radiator. However, science rovers must accommodate random orientations with respect to the surface and Sun. Terrain features can then result in hot environment sink temperatures beyond operating limits, even with shielded and articulated radiator assemblies. Lunar dust degradation on radiator thermo-optical properties can also significantly affect effective sink temperatures. During the Lunar night, heat rejection paths must be turned off to preclude excessive battery mass or properly routed to reclaim nuclear-based waste heat.

Science needs may drive rovers to extreme terrains where steady heat rejection is not otherwise possible. The paradigm of swarms or multiple smaller rovers enabled by commercial lander opportunities will need to leverage standard rover bus designs to permit flexibility. A heat pump provides the common extensibility for thermal control over the lunar diurnal. Active cooling systems or heat pumps are commonly used on spacecraft. Devices used include mechanical cryocoolers and thermoelectric coolers. For higher loads, vapor compression systems have been flown and, more recently, reverse turbo Brayton-cycle coolers are being developed under NASA's Game Changing program for high load, high temperature lift cryocoolers. However, technology gaps exist for mid-range heat pumps that are suitable for small science rovers where internal heat dissipation may range from 20 Watts to 100 Watts.

References

Apollo Lunar Roving Vehicle Documentation: <https://www.hq.nasa.gov/alsj/alsj-LRVdocs.html>

Apollo Experience Report - Thermal Design of Apollo Lunar Surface Experiments Package - <https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/19720013192.pdf>

Thermal Considerations for Designing the Next Lunar Lander: <https://aip.scitation.org/doi/10.1063/1.2437438>

Expected TRL or TRL range at completion of the project: 2 to 5

Desired Deliverables of Phase II

Prototype, Analysis, Research

Desired Deliverables Description

- Conceptual design
- Physics-based analysis or model
- Proof-of-concept hardware
- Final report

State of the Art and Critical Gaps

Specifically, heat pump systems are needed for the following:

- Temperature lift from a cold-side at < 50 deg. C to an environmental sink temperature as high as 75 deg. C (temperature lift of 50 deg. C or heat rejection rate of 230 W/m^2), with a system coefficient of performance > 2.5 .
- System should be tolerant of being powered down during the lunar night and re-started during the day reliably over multiple diurnals.
- Exported vibrations, if any, should be minimal for compatibility with science instruments.

Novel heat pump systems are desired. Enabling improvements over state-of-the-art systems are also welcome.

Relevance / Science Traceability

NASA's lunar initiative and Planetary Science Division form the primary customer base for this technology. Missions that directly address the NRC's Planetary Science Decadal Survey are included.

Scope Title

Software Improvements for Integrated Thermal-Structural-Optical Performance Analysis

Scope Description

Sensitive optical components and systems, as are frequently used on science missions, require structural, thermal, and optical performance (STOP) analysis in their design process to validate optical system performance in expected mission environments. This analysis often utilizes models generated in software unique to each field. The models, or their outputs, are transferred between analysts, creating iterative and time consuming design cycles. Software packages do exist that provide multiphysics analysis or coupling between analysis programs; however, the packages can be difficult to learn/implement and cost prohibitive. A new software is needed that can provide concurrent (or near concurrent) analysis using analysis programs in use by NASA, is straightforward to learn, and can be used by the growing number of low cost flight programs.

References

Nearly all spacecraft with optical components require some level of STOP analysis.

Structural-Thermal-Optical performance (STOP) Analysis:
<https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20150017758.pdf>

Expected TRL or TRL range at completion of the project: 5 to 9

Desired Deliverables of Phase II

Analysis, Software

Desired Deliverables Description

A successful STOP analysis software program will be applicable to any optical system and capable of interfacing with mechanical, structural, thermal, and optical analysis software used at NASA to provide concurrent (or near concurrent) analysis capability by users of the various disciplines. Additionally, the software must be straightforward to use and easy to learn.

State of the Art and Critical Gaps

STOP analyses have traditionally required a time-consuming, iterative approach where models, or their outputs, have been transferred among the respective structural, optical, and thermal analysts. Recently, multi-physics software packages have become available that can centralize the analysis into one program. However, these can be cumbersome to learn, lack heritage, and can be cost-prohibitive to use.

Relevance / Science Traceability

Any mission/project in which optical components or systems are used will require STOP analyses to be completed. As such, a general, integrated, and easy-to-use STOP software is a common desire among engineers of different disciplines.

Scope Title

Advanced Manufacturing of Loop Heat Pipe Evaporator

Scope Description

A loop heat pipe (LHP) is a very versatile heat transport device that has been used on many spacecraft. At the heart of the LHP is the evaporator and reservoir assembly. During the manufacturing, tedious processes are required to machine the porous primary wick and insert into the evaporator, and both ends of the wick need to be sealed for liquid and vapor separation. One commonly used method for vapor seal is to use a bimetallic knife edge joint, which is more prone to failure over long term exposure to thermal cycles and shock and vibration. These tedious manufacturing processes add to the cost of the traditional LHP. A new manufacturing technique that will allow the primary wick to be welded directly to the reservoir without the use of a knife-edge seal is needed in order to reduce the cost and enhance the reliability.

References

Richard, Bradley, et al., "Loop Heat Pipe Wick Fabrication via Additive Manufacturing," NASA Thermal & Fluid Analysis Workshop, August 21-25, 2017, Marshall Space Flight Center, Huntsville, AL

Expected TRL or TRL range at completion of the project: 4 to 6

Desired Deliverables of Phase II

Prototype, Analysis, Hardware

Desired Deliverables Description

- Successfully develop advanced techniques to manufacture the LHP evaporator and reservoir assembly.

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- Demonstrate the performance of the evaporator/reservoir performance in an LHP setup.
 - Final report.

State of the Art and Critical Gaps

The LHP evaporator contains a porous wick which provides the capillary pumping capability to sustain the fluid flow in the loop. The smaller the size, the higher the capillary pumping capability. On the other hand, the smaller the pore size, the higher the flow resistance which must be overcome by the capillary force. Traditional sintered metal wicks have a pore size on the order of 1 micron and porosity around 0.4-0.6. In order to replace the traditional porous wick, the new wick produced by the advanced manufacturing technology must have comparable pore size and porosity. The smallest pore size currently produced by direct metal laser sintering is on the order of 10 microns.

Relevance / Science Traceability

Traditional LHPs are used on many NASA missions including ICESat (Ice, Cloud, and Land Elevation Satellite), ICESat-2, Swift, Aura, Geostationary Operational Environmental Satellite (GOES), Geostationary Operational Environmental Satellite-R Series (GOES-R), and Surface Water and Ocean Topography (SWOT). Similar future SMD missions, especially those using small satellites, can greatly benefit from this technology.

Scope Title

Approaches and Techniques for Lunar Surface Payload Survival

Scope Description

The lunar environment poses significant challenges to small, low power (~100W or less) payloads, rovers, and landers required for lunar science. The lunar day/night cycle is approximately one earth month. During that time, surface temperatures on the lunar surface can reach 400K at local solar noon or drop to below 100K during the lunar night, even colder in permanently shadowed regions. These hot and cold conditions can last several earth days due to the slow rotation of the moon or permanently in shadowed craters. Lunar dust deposited on heat rejection surfaces and coatings will increase the heat absorbed from the Sun, thus reducing the effectiveness of radiators for heat rejection. The lunar gravity, which is 1/6th of the Earth's, will limit the ability of typical low power heat transport devices.

This call seeks to solicit innovative proposals to enable lunar science in the difficult lunar environment. Some technologies may include, but are not limited to, active loops that may be turned off and are freeze tolerate, zero or low power heat generation sources, high thermal capacitance thermal storage, advanced insulation, passive switching. Technologies should show substantial increase over the state-of-the-art. Considerations include power usage in day and night/shadow, mass, heat transport when turned on, heat leak when turned off, sensitivity to lunar topography and orientation, etc.

References

NASA Prepares for Performing New Science on the Moon:

<https://www.jpl.nasa.gov/news/news.php?release=2007-068>

Destination Moon: A History of the Lunar Orbiter Program - Chapter II: Toward A Lightweight Lunar Orbiter
â€“

The Surveyor Program: <https://history.nasa.gov/TM-3487/ch2-1.htm>

The Surveyor Program: <https://www.lpi.usra.edu/lunar/missions/surveyor/>

Missions - Lunokhod 01: <https://solarsystem.nasa.gov/missions/lunokhod-01/in-depth/>

Missions - Lunokhod 02: <https://solarsystem.nasa.gov/missions/lunokhod-02/in-depth/>

Expected TRL or TRL range at completion of the project: 3 to 4

Desired Deliverables of Phase II

Prototype, Analysis, Hardware

Desired Deliverables Description

Thermal management approaches, techniques, and hardware components to enable the accommodation of lunar temperature extremes encountered in the lunar environment.

State of the Art and Critical Gaps

Missions like Surveyor and Lunokhod hibernated during the night or reduced operational power near noon, in attempts to survive single or multiple lunar cycles. ALSEP's (Apollo Lunar Surface Experiments Package) were deployed on several Apollo missions and had select experiments that operated for many lunar cycles. However, both Lunokhod and ALSEP benefited from radioisotope heat and power sources, which are either too expensive or not likely to be available for near term future lunar science experiments. In fact, most modern lunar surface mission planning is based on solar power and batteries and typically avoids the challenges associated with surviving the full lunar cycle or shadowed regions.

While interest in lunar science and the development of abilities to deliver payloads to the lunar surface are resurgent, the capability to operate through the entire lunar environment is critical. In the absence of perpetual power supplies like RTG's, thermal management approaches to accommodate the lunar extremes, extended day/night cycles, and shadowed regions are seen as enabling.

Relevance / Science Traceability

SMD lunar surface science investigations will employ small, low power payloads that will require advanced thermal control approaches and techniques to survive and operate for extended duration through extreme thermal environments on the lunar surface.

NASA has plans to purchase services for delivery of payloads to the Moon through the Commercial Lunar Payload Services (CLPS) contract. Under this subtopic, proposals may include efforts to develop payloads for flight demonstration of relevant technologies in the lunar environment. The CLPS payload accommodations will vary depending on the particular service provider and mission characteristics. Additional information on the CLPS program and providers can be found at this link: <https://www.nasa.gov/content/commercial-lunar-payload-services>. CLPS missions will typically carry multiple payloads for multiple customers. Smaller, simpler, and more self-sufficient payloads are more easily accommodated and would be more likely to be considered for a NASA-sponsored flight opportunity. Commercial payload delivery services may begin as early as 2020 and flight opportunities are expected to continue well into the future. In future years it is expected that larger and more complex payloads will be accommodated. Selection for award under this solicitation will not guarantee selection for a lunar flight opportunity.